Next Generation Technologies for solar thermal electricity production

Robert Pitz-Paal, DLR
Direct Solar Steam Generation
Direct Solar Steam Generation
Thermo-hydraulics
Direct Solar Steam Generation

Control

Dynamisches Modell

Eintrittsmassenstrom
Direct Solar Steam Generation

Control

![Graph showing temperature, pressure, and direct radiation over time.](image)
Direct Solar Steam Generation

Component Optimization

Absorber Tube
(Temperature Image through glass envelope)

Compact-Steam Separators

Top View: coarse stage fine stage

Side View: 1.24 m
Direct Solar Steam Generation

Qualification

Flux distribution next to absorber tube
Direct Solar Steam Generation
Latent Heat Storage Technology

Lateinheatstorage
Latentspeicherung
durch Phasenwechsel
in der Salzschmelze
Direct Solar Steam Generation
System Optimization
A few words on Linear Fresnel Systems

The Linear Fresnel Design

- More simple design offers potentially lower investment cost
- Lower optical efficiency compared to parabolic troughs
- Therefore, high optical accuracy required
The steam producing principle is based on flat mirrors, concentrating the parallel solar radiation on a receiver tube. Inside the tube water is vaporised and directed to steam turbine.
NOVATEC BioSol – energy flow of a 10 MW Solar power plant

Beside production of electricity the surplus and exhaust thermal power can be used for chill production and seawater demineralisation.

- Annual collector eff. = 37%
- Annual Turbine eff = 25%
- Fresnel Total Annual Eff. = 9%
- Trough/Tower > 15%

Solarfield of 130,000 m²

23 GWh/a surplus 270°C usable for „Solar Cooling“
72 GWh/a steam 270°C
54 GWh/a exhaust steam energy 70°C
Usable for seawater Demineralisation of 700,000 m³/a

18 GWh/a electricity

10 MWₐr Turbine

- company factsheet -
The Solar Gas Turbine Approach

Solar Rankine

η = 16% (annual)

CC η = 25% (annual)
Experimental Experience at the PSA
Experimental Experience at the PSA using a small gas turbine

- Feasibility shown how to integrate solar high temperature heat a 800°C; 7 bar into a gas turbine
- Solar share up to 68%
- Good controllability at fluctuating irradiation
- Receiver exit temperature of >1000°C demonstrated
- Performance figures of design tools confirmed
### Long-term concept for a solar-fossil Combined-Cycle

#### Power block

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit(s)</th>
<th>Value(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas turbine (2 * V64.3)</td>
<td>kWe (ISO)</td>
<td>2 * 60'533</td>
</tr>
<tr>
<td>Steam turbine</td>
<td>kWe (ISO)</td>
<td>62'400</td>
</tr>
<tr>
<td>Total Power (design point DP)</td>
<td>kWe (DP)</td>
<td>158'900</td>
</tr>
<tr>
<td>Gas turbine inlet temperature</td>
<td>°C</td>
<td>1250</td>
</tr>
<tr>
<td>Annual power cycle efficiency</td>
<td>%</td>
<td>49.4/52.2</td>
</tr>
</tbody>
</table>

#### Solar-System

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit(s)</th>
<th>Value(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>solar input (DP)</td>
<td>W/m²</td>
<td>880</td>
</tr>
<tr>
<td>number of heliostats</td>
<td>-</td>
<td>2379</td>
</tr>
<tr>
<td>Total reflective area</td>
<td>m²</td>
<td>499'495</td>
</tr>
<tr>
<td>rec. outlet temperature (DP)</td>
<td>°C</td>
<td>1100</td>
</tr>
<tr>
<td>aperture of single module</td>
<td>m²</td>
<td>1.28</td>
</tr>
<tr>
<td>total receiver aperture</td>
<td>m²</td>
<td>734.4</td>
</tr>
<tr>
<td>number of rec. modules</td>
<td></td>
<td>572</td>
</tr>
<tr>
<td>total receiver power</td>
<td>kWth</td>
<td>227'000</td>
</tr>
<tr>
<td>Optical tower height</td>
<td>m</td>
<td>220.0</td>
</tr>
<tr>
<td>Annual solar to heat eff.</td>
<td>%</td>
<td>41.4</td>
</tr>
</tbody>
</table>
Cost assumptions
Investment

- „Levelized Electricity Cost (LEC)“ based on IEA method
- Interest rate 7%
- Depreciation time 20 a
- Site Barstow (California, USA)
- Annual direct irradiation 2791 kWh/m²a
- Fuel price varied (today around 17 €/MWh in US)

Additional Investment

<table>
<thead>
<tr>
<th>Solar</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site preparation [€/kWe]</td>
<td>6.500</td>
</tr>
<tr>
<td>Buildings [T€]</td>
<td>2.250</td>
</tr>
<tr>
<td>Electrical equipment [T€]</td>
<td>2.50</td>
</tr>
<tr>
<td>Auxiliary equipment [T€]</td>
<td>1.50</td>
</tr>
<tr>
<td>Total [T€]</td>
<td>5.195</td>
</tr>
</tbody>
</table>

Indirect cost

<table>
<thead>
<tr>
<th>Solar</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction (9%) [T€]</td>
<td>17.463</td>
</tr>
<tr>
<td>Management (10%) [T€]</td>
<td>19.403</td>
</tr>
<tr>
<td>Contingencies (3.5%) [T€]</td>
<td>7.761</td>
</tr>
<tr>
<td>Total [T€]</td>
<td>42.062</td>
</tr>
<tr>
<td>Total [T€]</td>
<td>236.095</td>
</tr>
<tr>
<td>Specific (related to. DP-power) [€/kWe]</td>
<td>611</td>
</tr>
</tbody>
</table>

[Image of a slide showing a table with financial data and calculations related to solar power systems and cost assumptions.]

---

**Note:** The table and calculations are related to solar power systems and cost assumptions, including site preparation, buildings, electrical equipment, auxiliary equipment, and indirect costs. The costs are detailed in Euros (€) and Table Euros (T€).
LEC in Mid-load Operation

4000 full-load hours

Fuel price [€/MWh]

LEC [€/kWh]

- Reference
- Hybrid

Solar LEC

0€/t CO2;
7% interest
20 years
125€/m² Heliostat
44% solar share

Reference

Hybrid
Impact of CO2-penalties, interest rate and heliostat cost

4000 full-load hours

- 20€/t CO2
- 5% interest
- 20 years
- 100€/m² Heliostat
- 44% solar share

LEC [€/kWh]

Fuel price [€/MWh]
How to go there…

The diagram illustrates the cost of solar electricity as a function of solar system size. The data points show the cost of electricity (solar LEC) in euros per kilowatt-hour (€/kWh) for different system sizes, ranging from small systems (1-30 MWth) to big systems (60-230 MWth) in various configurations, such as north field and multi-aperture. The trend indicates a decreasing cost with increasing system size, reflecting economies of scale.

Key points:
- Small systems (1-30 MWth) show a lower cost per kWh compared to big systems (60-230 MWth).
- The trend line suggests a consistent decrease in cost with the size of the solar system, which is particularly pronounced for the larger systems.

Additional note: The 160 MWc CC solar share is 80% DP and has a 44% annual performance.
Summary

- High efficient solar power plant for mid-load power
  - Solar-to–electric efficiencies > 20%
  - Fuel-to-electric efficiency > 50%
- Low environmental profile
  - 25% of cooling water compared to parabolic trough plant
  - No thermal oil!
  - Can be applied in hilly area
- Low cost
  - Specific investment cost <1500 €/kWe
  - LEC = 7 €cent/kWh for 160 MWe power plant
- Scale-up
  - Starting with small turbines (eventually combined with CHP)
  - Hybridization with Biofuel (up to 50% feasible in Spain)
Thank you for your attention!